Final Technical Report

Pacific Northwest Seismic Network Operations - EHP

USGS Cooperative Agreement G15AC00054
1 February 2015 - 31 January 2020

Harold Tobin
The University of Washington
Seattle, WA 38152
Ph: (608) 770-8307
Fax: 206-685-5788
htobin [at] uw [dot] edu

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Abstract

This report summarizes in brief form the activities of the Pacific Northwest Seismic Network (PNSN) during the term of the 5-year Cooperative Agreement between 1 February 2015 and 31 January 2020. The period has witnessed tremendous growth of the network operations and responsibilities. Much of this growth and development has been, strictly speaking, external to this particular Cooperative Agreement, and accommodated by other agreements and sponsors that are more targeted in their scopes. However, this agreement funds the core of the PNSN operations and provides the glue that binds all the others together, guides PNSN's conformance with ANSS (Advanced National Seismic System) policies, performance, and goals, and provides for participation of PNSN in informing and advising the ANSS federation of seismic networks. The big picture overview is that this 5-year agreement has seen the network make tremendous strides toward the evolution of greater automatic data handling, processing, and procedure monitoring. In the future, this will become ever more important and necessary as the sheer quantity of data grows (more data channels, digital acquisition). Also, it becomes more powerful as technology advances and our ability to track performance is enhanced. These developments require a tremendous upping of an RSN's game while facilitating the eventual implementation of new techniques and products to advance

ANSS's goals. It is also exposing limitations of the network operation and approach to station siting and permitting and requiring changes really in every element of the network, from data telemetry, through IT network security and data flow, algorithmic processing, and notification and communication. All done while maintaining 24/365 coverage and availability.

> **Goals of the ANSS Relevant to RSNs**
>
> 1. Establish and maintain an advanced infrastructure for seismic monitoring throughout the United States that operates with high performance standards, gathers critical technical data, and effectively provides information products and services to meet the Nation's needs. An Advanced National Seismic System should consist of modern seismographs, communication networks, data processing centers, and well-trained personnel; such an integrated system would constantly record and analyze seismic data and provide timely and reliable information on earthquakes and other seismic disturbances.
>
> 2. Continuously monitor earthquakes and other seismic disturbances throughout the United States, with special focus on regions of moderate to high hazard and risk.
>
> 3. Thoroughly measure strong earthquake shaking at ground sites and in buildings and critical structures. Focus should be in urban areas and near major active fault zones to gather greatly needed data and information for reducing earthquake impacts on buildings and structures.

Report

A Regional Seismic Network (RSN) is like a Swiss Army Knife—a multi-purpose set of tools in a single efficient package. The RSN provides ground motion data, and seismic data products derived from the recorded ground motions, for a number of purposes and stakeholder interests. It also provides a local "face" for seismic information, and particularly in the case of the USGS Earthquake Hazards Program (EHP), for information about regional seismic hazards and risk mitigation. But the Swiss knife multi-tool simile is apt because RSN data are used by a wide variety of stakeholders for a wide variety of purposes.

In the following sections we provide summaries of network and data center operations. The report is organized very roughly in the way seismic data is passed through the system. That is, we will first talk about data acquisition and processing issues, including the delivery and availability and the exchange of data and data analysis products. Then summarize activities at the data center, including product generation and dissemination. And then it's on to outreach and hazard communication. And we will summarize and illustrate how PNSN coordinates with other RSNs and with the EHP, including discussions of ComCAT, SIS, AQMS, and other ANSS-sponsored systems.

<u>Project Data—Collection and Public Availability of PNSN Data</u>

Seismic data available for use in meeting ANSS goals and funded by this agreement to be collected, managed, and archived for open use leads to the consideration of several categories:

a) Data from stations operated and maintained directly by the project, all of which bear the UW network code.
b) UO network code data, which can be considered to be jointly installed and operated with the University of Oregon (UO) but because the operations are so intertwined, can be complicated to separate.

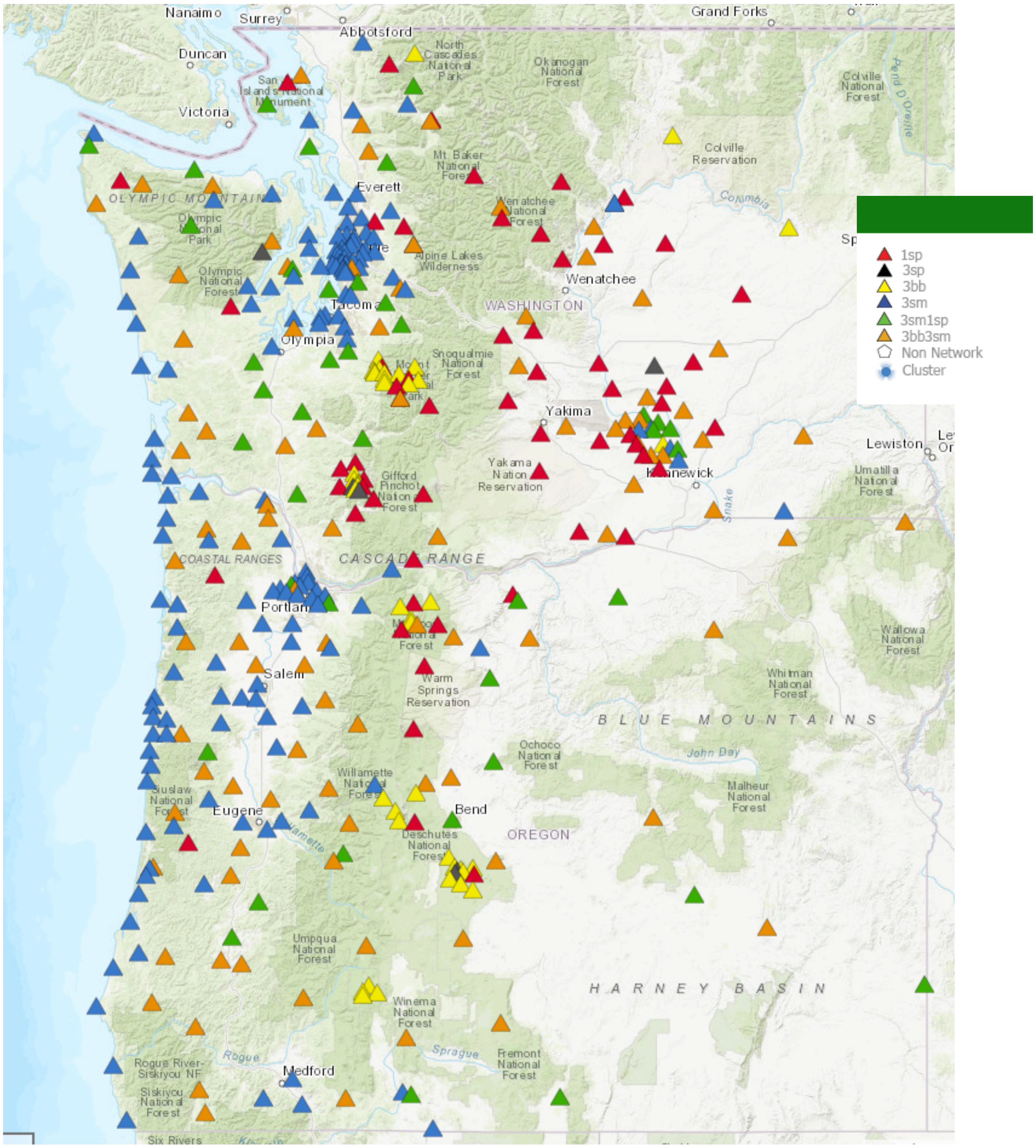

Figure 1: Map of seismic stations within the UW, UO, and CC networks. Station types as indicated in figure legend. 1sp=single vertical short period, 3sp=3 component short period, 3bb=3 component broadband, 3sm=3-component accelerometer, 3sm1sp=4-channel, 3sm3bb=6-channel.

c) Data from stations operated and maintained by UW, but the operation of which is funded by agencies other than USGS EHP. These include the Hanford area stations in eastern Washington, whose installation and maintenance is funded by the Departement Of Energy (but also labeled with the UW network code). And also, the USGS Volcano Hazard Program (VHP), which stations are operated cooperatively with the Cascade Volcano Observatory, and use the network code CC.
d) Occasionally data may be collected from temporary deployments, during aftershock or swarm sequences, for example, or for a targeted data collection experiment. These temporary station data often are assigned the UW network code and become part of the permanent regional seismic data archive and are used in local re-processing of the data.
e) Data contributed by other networks, but for whom PNSN assumes responsibility for importing for regional seismic hazard purposes, and with whom we coordinate (IU, US, CN, NN, NV, OO, NC, BK, PB, MB, GS). Data from these stations are used in the generation of real-time and post-processed products, but neither PNSN nor USGS operates these stations (except the US and GS network stations), nor funds their operation.

Table of Seismic Station Counts Used in PNSN

Summary Statistics for Regional/Urban Seismic Network	Number (unique sites)	Station Response Information in dataless SEED volume(s)
Total no. of stations operated and/or recorded	**739* (616)**	Yes
Total no. of channels recorded	**2250$**	Yes
No. of short-period (SP) stations	**162***	Yes
No. of broadband (BB) stations	**189***	Yes
No. of strong-motion (SM) stations	**388***	Yes
No. of stations maintained & operated by network	**625*# (487#)**	Yes
No. of stations maintained & operated as part of ANSS	**698*# (455#)**	Yes

***** *This count does not represent the number of individual sites, but rather recognizes each different channel types (i.e. SM, SP, and BB) as a separate station if they are present at a site. Therefore, a site with a short period vertical channel as well as 3 SM channels counts as two stations (1 SP, and 1 SM) and a site housing 3 broadband and 3 strong-motion channels would count as two stations (1 BB, 1 SM) as well.*
*Only includes UW, UO, and CC network codes; the other numbers also include stations from networks OO, PB, NV, US, IU, NP, NC, BK, MB, and CN.*
$ *This channel count is for seismic data channels only. State-of-health (SOH) channels are also recorded and archived. At this time 3282 SOH channels are being imported into the PNSN system.*

Most of these data are acquired continuously in real-time (an exception is the NetQuakes initiative discussed below). And for categories *a-d* above, PNSN assumes responsibility for managing the metadata not only to use the data in regional processing, but also in reporting the seismic data to the seismic data archive at the IRIS DMC (Incorporated Research Institutions in Seismology Data Management Center). All of the seismic waveforms are passed into the PNSN's ANSS Quake Management System (AQMS) system in the seismo lab at the University of Washington, Seattle, campus. The data are automatically scanned to detect and locate local earthquakes. Every detected earthquake is reviewed, ultimately, by a human analyst. Automatic locations meeting certain criteria, and reviewed locations, are passed onto the Product Distribution Layer (PDL) and on to the National Earthquake Information Center in Golden, CO. They are also published on PNSN's website (pnsn.org). Additionally, several different types of seismic data products, which will be discussed below, are produced and distributed into PDL and/or onto our local web pages.

All of the seismic data used in the creation of all of the products PNSN generates is stored in a local Winston Wave Server archive for about 1 year. And within tens of seconds of their acquisition, data from categories *a-d* are passed to the IRIS DMC via an Earthworm-SeedLink server process to be permanently archived. This whole process usually takes place in less than 30 s from the time of acquisition in the field (a recent non-exhaustive survey of the IRIS's BUD monitor (http://www.iris.washington.edu/bud_stuff/dmc/bud_monitor.ALL.html) found most data being available in the archive with total latencies under 10s). Moreover, via agreements between PNSN and surrounding networks (NCSN, BSL, Canada, Montana, and USNSN/NEIC) we export to each of them our real-time seismic data for stations in which they are interested. We also exchange real-time seismic data directly with the nation's two Tsunami warning centers (NTSWC and PTSWC), for use in generating tsunami warnings.

Another nuance that affects inventory and accounting procedures within PNSN is the inclusion within the network of seismic stations with "hybrid" ownership. This particularly affects some stations in categories *a-b*. At some stations, for example, different stakeholder agencies and sponsors may contribute equipment, but the station data acquisition and processing, and even the station maintenance might be accomplished with funding provided by this agreement. Such situations arise where the station's data is needed to provide products that meet ANSS regional goals.

Two subnetworks are deserving of special mention: NetQuakes, and the geotechnical monitoring array at station SLA (Seattle Liquefaction Array) in downtown Seattle.

The NetQuakes initiative is an early foray into using inexpensive MEMS sensors and contributed WiFi telemetry to densify urban accelerometer networks. By partnering with home owners and/or business owners and using their Internet networks, the NetQuakes model envisioned reduced operating costs and effort. Moreover, it was thought that when sites acted up, a station host with minimal experience or skill could pack up the instrument and exchange it for a working one. Several years ago, however, a significant and dangerous problem at a station in California led to all of the NetQuakes installations being shut off until a repair was determined. Since that time the PNSN NetQuakes array has struggled to recover. Currently 78 NetQuake instruments are deployed in PNSN, but fully a third of those were never able to be fixed and re-started. The failure of the operating model in this case (host-provided maintenance) requires site visits and has resulted in the repairs being assigned lower priority when competing with more valuable data (*i.e.,* high-quality real-time stations).

The SLA is a state-of-the art geotechnical monitoring array in south Seattle at a site that repeatedly liquefied during earthquakes in 1949, 1965, and 2001. The array consists of 6 piezometers at depths between the surface and 15.7 m deep. There are also accelerometers at the surface and at depths to 56 m. Until now the site has experienced no shaking strong enough to generate excess pore-pressure, but PNSN is enthused to operate and maintain the data flow from this important array, together with colleagues at the USGS and University of California, Santa Barbara (Jamie Steidl).

Acquisition telemetry

Historically, PNSN operated many analog stations, and because of regional constraints (low insolation, trees, visibility concerns, topography, access difficulty, snow load, *etc.*) it has been, and remains, difficult to transition monitoring to strictly digital modes. Nevertheless, the analog network is slowly being phased out and replaced where possible by digital data acquisition and telemetry. We have adopted a strategy of trying to replace individual circuits that generally transmit data from a geographic area. And with past ARRA funding and EEW support we have been able to do that for a number of circuits. But many still remain. It is not possible at this point in time just to shut off the old stations, because the new network is generally less dense and occupies different locations (generally noisier being nearer to cultural noise sources). This would reduce our detection capabilities and endanger the network's ability to characterize changes in baseline seismicity patterns.

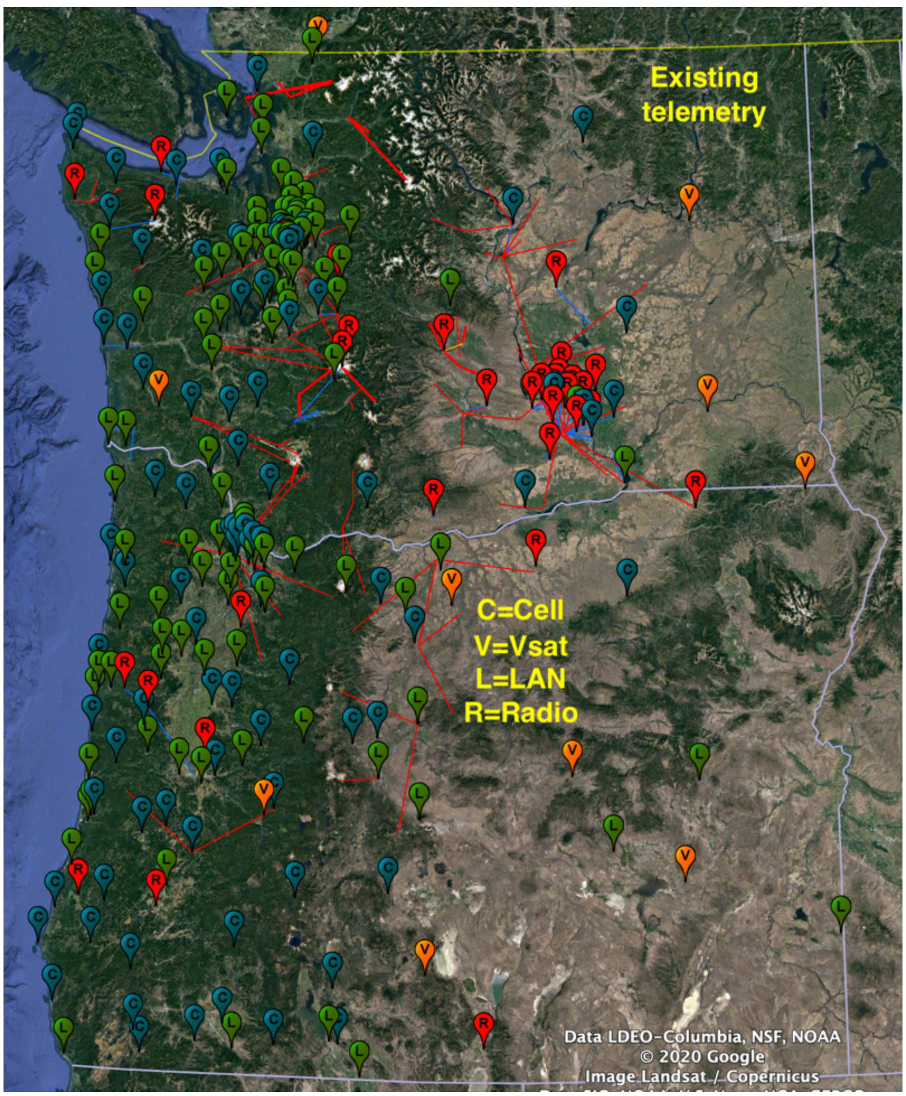

Figure 2: Seismic data telemetry within the UW and UO networks. This figure shows each site, coded by its primary data transport modality as it exists today in the PNSN station network.

The resulting current telemetric network, as revealed in Figure 2, is heterogeneous in mode, and complicated in layout. Details of the network are too grisly for this report, but contain a full suite of, in addition to our old self-maintained analog FM radio net, Cellular data, VSAT satellite data, public Internet (including use of the WA state K-20 educational network), data lines leased from commercial providers, and provided (sometimes at a cost) by local government or public service entity. For remote stations, we often use our own digital radios to bridge the "last mile" between the seismic acquisition station and a point of demarcation to whatever digital data backhaul to Seattle is being used. It is important to realize that while the RSN is technically just a data telemetry network connecting seismic appliances at the ends to the processing center, the seismotectonic and hazard needs of the ANSS goals guide the geographic distribution of stations and types, and the telemetric capabilities are worked out to service the resulting distribution and station locations.

Data Center Operations

The PNSN data center at UW manages the data flow and processing and the production and distribution of seismic data products. This includes not only the central planning and coordination of network activities, but also the treatment of metadata, the configuration and security of the IT networks and computing environment, the distribution of data products, and interpretation of seismic phenomena for regional stakeholders in pursuit of PNSN's and ANSS's joint goals.

Over the term of this agreement, PNSN staff has grown to more than 30 positions, a number of them funded by this agreement. During the past year, under the new leadership of director Tobin, PNSN is implementing a new management structure. There are now 4 "teams", each representing a critical element of PNSN operations: Engineering, IT/computing, Products & Processing, and User Engagement. Each team has a lead and the team leads, together with Tobin, Bodin, and the chiefs of the USGS PNSN and University of Oregon PNSN projects, constitute the leadership group. The leadership group meets regularly to set goals, define projects and review progress on them, and identify and mitigate any roadblocks.

A good and relevant example of how this works is the development and implementation of the AQMS system using the PostgreSQL database. When AQMS was introduced to PNSN in 2012, it was served on USGS-provided and owned SUN hardware and used the proprietary Oracle database. PNSN management recognized that this was unsupportable in the long run and started a project, ultimately funded by the Gordon and Betty Moore Foundation, to migrate the AQMS system to PostgreSQL. The Processing/Products team (and its predecessors) worked with other ANSS networks, a private seismic software company (ISTI) to review and re-write the AQMS system. Meanwhile the IT/computing team acquired and configured the hardware and IT network to be able to handle the changes, and User Engagement coordinated with the funders in order to support the effort. As a result, a fully implemented AQMS system that is agnostic as to which underlying database is used (either Oracle or Postgres) was developed and that has been in production in PNSN for the past couple of years. Moreover, the PostgreSQL version of AQMS is now being adopted by other RSNs.

At the UW data center, in addition to our principal full-time data analyst (Amy Wright) a half dozen UW staff are on a rotating Duty Seismologist role. At any given time, there is a Duty Seismologist (DS) and a Backup Duty Seismologist (BDS). The DS/BDS carry pagers and are alerted to automatic earthquake locations and to a variety of system alerts and conditions. All of our review procedures (like Jiggle) and data quality products (discussed below) are available from off-campus. In the PacNW, M>3 earthquakes are designated as "alert" earthquakes and our policy is to have one of the DS crew quickly visually review and manually confirm any automatic location at this threshold. When, after review, the earthquake is verified and relocated the DS notifies the appropriate Emergency Operations Center (EOC) in either Oregon or Washington to confirm that notifications sent automatically via pager and e-mail to the EOC was received. This "DS crew" coverage ensures that all alert earthquakes are reviewed, validated, and notifications sent within a few minutes of the origin time.

PNSN produces a suite of data and impact products in addition to raw seismic data. Most of these products are available to the general public on the PNSN website, as noted below. The PNSN website is hosted on the Amazon Web Services cloud, where the front-end processes are deployed in such a framework that should requests overwhelm them, then more servers and workers are spun up automatically, and advanced page caching protocols are employed to reduce costly requests. Meanwhile, the products are generated on the backend servers at the UW Data Center, and their generation is a relatively constant and manageable load on the systems.

Products include:

- **Raw data for ShakeAlert Earthquake Early Warning.** The UW data center is one of four nodes on the west coast for producing ShakeAlert notifications. PNSN is responsible for providing the raw data to the ShakeAlert production systems. (These low-latency data feeds are **not** publicly available).
- **Day-long seismograms** ("Webicorders" for every data channel: https://pnsn.org/seismograms/map)
- **QuickShake** (high-rate streaming "live action" seismograms): http://quickshake.pnsn.org
- **Near Real Time Waveforms** (low-rate stream of seismograms for a handful of tell-tale PNSN seismic stations): https://assets.pnsn.org/realtimeplots/
- **Spectrogram** access (Colorful spectrograms for both volcanoes and tectonic sub-regions of PNSN): https://pnsn.org/spectrograms
- **REDPy** (The Repeat Earthquake Detector finds and analyzes the occurrence of "families" of earthquakes at several of the region's most dangerous volcanoes): http://assets.pnsn.org/red/
- **First motion Focal Mechanisms** (While we do not currently produce Regional Moment Tensors we do calculate and present first-motion mechanisms): example: https://pnsn.org/event/61618306#technical-data
- **Regional non-volcanic tremor** (our widely used and cited implementation of the popular "Wech-o-meter"): https://pnsn.org/tremor
- **Volcano seismic activity** (special web pages with background information and current seismic activity at the region's volcanoes): https://pnsn.org/volcanoes
- **ShakeMaps** (we produce special high-resolution versions of the ShakeMaps we provide to NEIC for two regions: the Seattle metropolitan area, and the Hanford site): example at https://pnsn.org/shakemaps/61293181
- **ShakeCasts** for regional events are not produced by us, however our customers at the Hanford Nuclear Facility want us in the loop with Dave Wald's group so we work with the Hanford site's emergency managers to keep the ShakeCast system working and to provide interpretative expertise.
- **Catalog search** (PNSN's local search-and-plot site that can produce targeted searches and make some quick graphs, like cross-sections and cumulative number plots, *etc.*): https://pnsn.org/events?custom_search=true
- **Notable events** (Special event information for earthquakes that stimulated popular

interest or concern): https://pnsn.org/earthquakes/notable

The entire archived seismicity catalog generated by PNSN has been loaded into ComCAT. Because we also provide catalog searches through our website, we ensure synchronicity of the two publicly-available using an automatic polling process.

SIS and Inventory:

Keeping track of all of the station inventory and ownership situations as outlined above, as well as the "wiring" of the network's data flow and the seismic response of the individual channels, is the province of the Station Inventory System (SIS). Considerable effort at PNSN has been made to implement and populate SIS over the term of this agreement. Any and all new or upgraded stations are fully integrated into SIS, and staff are trained in using it to report network changes. We have not yet completed loading a comprehensive archive of our historical station metadata. While we have written and tested scripts for handling the more than 5 decades of analog station metadata, the work required to apply the scripts, check the reliability and accuracy of the resulting database entries is substantial and it has received a lower priority in competition with more pressing needs. That is because at a large and long-lived network like PNSN there are many unique situations or other problems that can trip up the script, requiring hand-curation and oversight of the SIS-incorporation process.

Permitting, Land Use Agreements:

The requirements for regional seismic monitoring dictate that the geographic distribution of stations should be governed by the hazard and the risk. For this reason, an RSN needs to identify and work with landowners to access, construct, and operate seismic equipment on the landowners' property. Moreover, the station and land itself must satisfy local and federal permitting regulations to ensure compliance with safety, security, and environmental needs. For an RSN with hundreds of seismic stations and dozens of telemetry nodes and points of presence, this leads to a complex web of agreements, permits, and arrangements. PNSN has permits, access agreements, and understandings (both formal and informal) with private citizens, companies, and local and state agencies. Managing, overseeing, and documenting this element has grown into a major task in and of itself, as the number of stations increases, and the administrative requirements become more insistent.

The past 5-year period has seen a growth in the need to corral and formalize this critical element of network operations. For example, USGS and ANSS policy is that any station receiving support from USGS must meet NEPA permitting requirements, which means nearly every station PNSN operates. PNSN does this currently via a number of mechanisms, descriptions of which follow, but increasingly this is being organized and tracked with uniform well-documented procedures and databases. This is bringing order out of chaos, but is an ongoing project. It is also important to recognize that different PNSN partners (the USGS and UO and UW) may negotiate and enter agreements independently, so the mechanism for documenting and tracking the agreements must cross institutional boundaries. Within the UW, the University real estate office negotiates and holds many agreements, but particularly those that have financial costs associated with them. Every new station has its related agreements documented in an online database maintained on UW servers. These agreements can be pointed to by remarks in the SIS system, too. For NEPA approvals we use a process that directly involves USGS procedures and personnel. PNSN staff acquire information needed to classify and permit the site; the information is assembled into a report by an external contractor, and the report is delivered to USGS personnel to apply and obtain the needed NEPA classification. Currently, all of these records are kept within our own archives, but we are planning to organize them into a commercial document storage and maintenance system (the Atlassian suite of collaboration software tools).

Station State-of-Health

Modern seismic data acquisition systems, including not only the sensors and dataloggers, but also the ancillary equipment like electric power regulators and battery chargers, cellular data modems or digital radios, routers and switches, all have the ability to self-monitor and report on their status and states of health. There is a tremendous upside to this: it allows us to detect and diagnose problems remotely and to be proactive in our maintenance. We find that after a period of “burn in”, fully digitalized stations (usually) require less frequent field visits to correct. [It is worth noting that field visits are still valuable to maintain landowner and stakeholder relationships]. However, there is also a downside in that the networking required for the digital stations can be problematic. And even more critically, all of the components may be vulnerable to intrusion and subject to technological changes (generally, although not always, improvements), and so must be monitored, hardware and firmware regularly updated, *etc.* PNSN tracks this type of data via a variety of mechanisms, chiefly SeisNetWatch, and, increasingly, Nagios. Station and network state-of-health data is, in itself, a complex data ecosystem parallel and increasingly critical to support the seismic data ecosystem.

Performance Monitoring

Ensuring that the data being collected and archived at PNSN are acceptable within the definitions and requirements of the ANSS Performance Standards requirements is increasingly challenging and, perhaps paradoxically, potent. In PNSN different performance metrics about seismic data serve different purposes and should be measured at different locations and using different techniques. As just one example, the data PNSN supplies to the ShakeAlert EEW system must have the lowest possible latency. The latency is measured on the ShakeAlert production systems’ servers via an algorithm developed at CalTech in the aftermath of the 2019 Ridgecrest, CA, earthquake. On the other hand, most of our data quality metrics are most sensibly and best made on the data that we archive at the IRIS DMC. Those are the data that the world sees and uses, and that have passed through our myriad processing systems. PNSN has been actively developing data quality monitoring tools. Two deserving of special mention include SQUAC (the Seismic Quality Assessment Console (http://nmc-design.com/squac.html) and MUSTANGular. SQUAC is configured and populated via a RESTFul API allowing operators to interact with the application through any programming language or web service they choose. The web team has received funding from IRIS to design and build MUSTANGular. MUSTANGular is used to map MUSTANG analytics using an interactive and responsive application. (http://ds.iris.edu/mustang/mustangular/#/form).

An important goal of performance monitoring is to document the robustness and accuracy of the data products. Degraded performance of an individual station or data channel can have different impacts, ranging from severe to insignificant, depending on numerous factors (nearby station density, noise levels, purpose, *etc.*). An example of a metric that can be tracked is the detection magnitude threshold at any given moment depending on the network state and the noise level. We have been developing MagD to provide this metric. MagD is a Python port of USGS scientist, Dan McNamara’s code to analyze a seismic network’s ability to detect earthquakes, with the results displayed as a contour map (https://github.com/pnsn/magd_client, examples in notebooks at https://github.com/pnsn/magd_client/tree/master/notebooks).

Continuity of Operations Planning

Preparing for emergency situations and operations has been an ongoing focus and goal of PNSN during the past 5-years. Until this year, we focused largely on being able to operate the network remotely from off-site. This has served us in good stead during the COVID-19 pandemic, too, as we've been able to continue operating the network without significant pause in data acquisition and quality, or product generation. We continually review the Continuity of Operations plan…even though the last published version was early in this 5-year Coop agreement period (2016). In the midst of the coronavirus pandemic crisis, it is instructive and poignant to reproduce in full the plan's specific reference to pandemics:

> (**Risk #10 – Pandemic, Chemical stockpile leak, etc.**
>
> Other risks we are subject to include Pandemic (*e.g.,* influenza), or chemical leaks from surrounding buildings and similar events. These events may require us to shelter-in-place (work at home or stay at the office), or we may have to evacuate from Seattle. In the event we have to leave the city, we could transfer operations to a partner organization and/or relocate to an alternate site outside of the Puget Sound (or impacted area) and resume work.

While we gave the specific underlying threat short shrift perhaps, the structure and procedures embodied in the plan have permitted us to continue operating at a high level of efficiency and readiness for the past six weeks.

Working with Regional Stakeholders

PNSN is in frequent communication with our regional stakeholders, particularly the emergency management officials in the state of Washington. The two most relevant state government organizations in Washington are the Office of Emergency Management (Washington Military Department) and the Department of Natural Resources. PNSN Director Harold Tobin also serves as the Washington State Seismologist. PNSN/UW staff (Tobin, Bodin) also sit on the Washington State Seismic Safety Committee (https://mil.wa.gov/seismic-safety-committee-ssc). In Oregon, the past five years has seen more active engagement of PNSN/UO staff with the Oregon state stakeholders. With NGOs, PNSN personnel are members, including in leadership positions, in WSSPC (Western States Seismic Policy Council) and CREW (Cascadia Region Earthquake Workgroup).

We have regular coordination with our Canadian counterparts. Not only operationally through our real-time data exchange and coordination for earthquakes that, because of proximity, impact both countries. But also we are planning for initiatives of mutual importance such as offshore monitoring and Canadian participation in ShakeAlert Earthquake Early Warning.

Regional Seismicity

In terms of earthquake occurrences, the past 5 years have been typical for the Pacific Northwest. Catalogued events account for only about 10% of system "triggers" (~90% of our triggers are caused by noise or teleseismic phases). All triggers are at least looked at by a PNSN staff seismologist, and we estimate that we've reviewed at least 250,000 signals in the 60 months covered in this report.

11,113 earthquakes and 2,860 explosions (or probable explosions) and 51 "low-frequency" or deep long-period (DPL) earthquakes), all of these earthquakes added to the catalog were larger than M = -1 and were provided to the USGS Earthquake Hazards Program ComCat via PDL. 10,569 exceeded magnitude 0, 4,873 exceed magnitude 1, 650 exceeded than magnitude 2, 70 exceeded magnitude 3, and 8 exceeded magnitude 4.

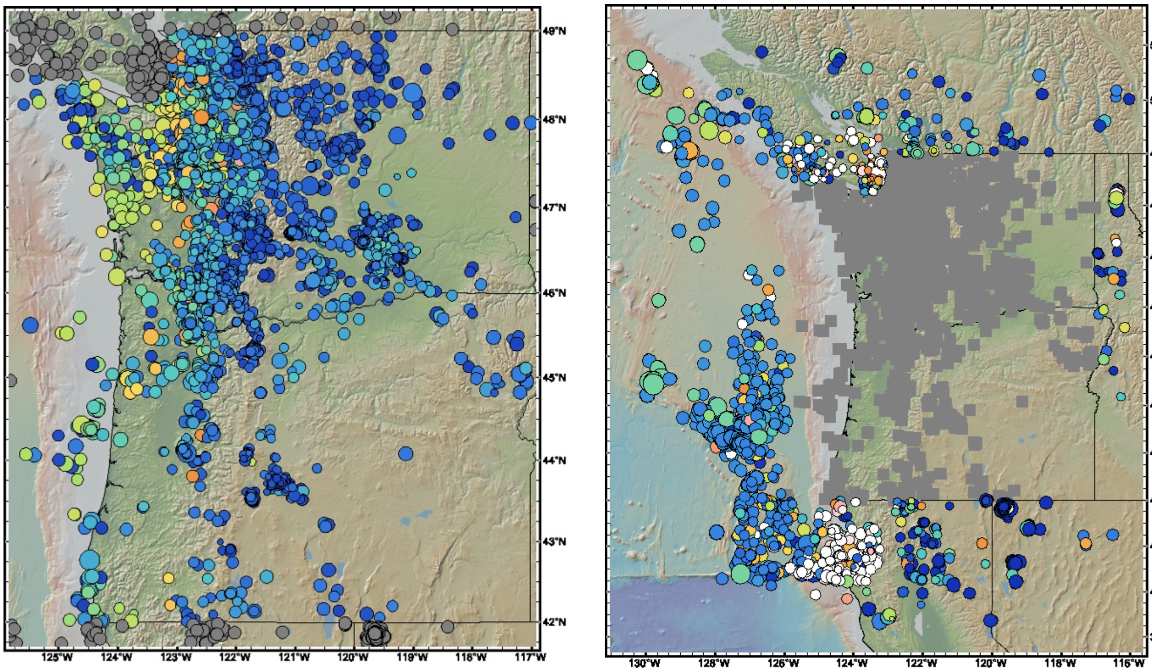

Figure 3: Map of earthquakes located by PNSN during the reporting period. Left: Local earthquakes catalogued and reported (i.e. authoritative) by PNSN during the term of this Co-op agreement symbol sizes proportional to magnitude, color is hypocentral depth: cool-shallow, warm-deep. Right: Regional earthquakes located by PNSN. Grey squares are the authoritative regional earthquakes from the left panel.

Funding expended for the term covered by the report

All Funds for this report were spent according to the proposed timeline. We did not request any carryover.

The UW Office of Contracts and Grants prepares the SF425 form that accompanies this report.

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